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FATIGUE CRACK PROPAGATION IN TITANIUM ALLOYS.(U)
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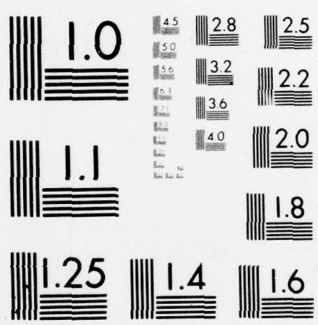

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ANNUAL REPORT

FATIGUE CRACK PROPAGATION IN TITANIUM ALLOYS

GRANT AFOSR 74-2703

NOVEMBER 1977

Principal Investigator:
A. J. McEvily, Professor
Metallurgy Department
University of Connecticut
Storrs, CT. 06268
(203) 486-4620

Submitted to:
Air Force Office of Scientific Research (AFSC)
Department of the Air Force
Bolling Air Force Base, D.C. 20332

Attn: Mr. William Walker
Program Manager

(See 1473)

ANNUAL REPORT

This report reviews the research accomplished on the fatigue of Ti-6Al-4V forgings and related research for the period 1 July 1976 to 30 September 1977. The research has involved studies of fatigue crack initiation as well as fatigue crack propagation. A principal effort has been directed toward the understanding of the causes of subsurface fatigue crack nucleation, and a study involving transmission electron microscopy of fatigued specimens has been carried out to elucidate the fatigue mechanism involved. A principal objective of the study of fatigue crack propagation has been directed at the understanding of overloads and the associated retardation of fatigue crack growth. In addition the general nature of the crack closure phenomenon has been investigated and further insight into the mechanisms of fatigue crack growth as a function of stress-intensity factor range have been obtained.

Fatigue Crack Initiation

During the report period, attention has been directed at the determination of the nature of the dislocation arrays present in fatigued Ti-6Al-4V forgings, particularly in the high cycle region where subsurface initiation of fatigue cracks is most often encountered. We have observed isolated pile-ups of edge dislocations at α-β interfacial regions with as many as 50 dislocations present in a single pile-up. Calculations have been carried out to determine the magnitude of the friction stress based upon the spacing of the dislocations in the off-loaded conditions as observed by transmission electron microscopy. This stress is of the order of 10,000 psi, so that extremely high net stresses can be developed at the

head of the pile-up of planar edge dislocations. This high stress is necessary, but perhaps not a sufficient condition for crack initiation, and we are currently investigating the possibility of internal hydrogen embrittlement to facilitate the initiation of a crack at the head of a pile-up. The crack may then propagate by a Stage I mechanism along prism planes before developing into a Stage II crack. That such a process of crack initation and growth may be taking place is suggested by the work of D. Eylon and J. A. Hall "Fatigue Behavior of Beta Processed Titanium Alloy IMI 685," Met. Trans. 8A, p. 981, 1977. Experiments to be carried out include the effect of a hold time under load on the number of cycles to failure. If hydrogen embrittlement is important, then this hold may lead to a decrease in the number of cycles to failure as observed by Eylon and Hall. In addition X-ray microfocus analysis to determine the crystallography of the plane of initial cracking will be carried out. Preliminary results indicate that it may indeed be a prism plane, consistent with a Stage I mode of cracking across an α-colony.

We plan to present the results of this study at the ASTM meeting on Fatigue Mechanisms which is to be held next Spring in Kansas City, Mo. (J. Ruppen and A. J. McEvily,"Effect of Cyclic Loading on the Dislocation Arrays and Crack Initiation Process in Ti-6Al-4V").

A paper "Influence of Microstructure and Mean Stress on the Fatigue Behavior of Ti-6Al-4V" by R. K. Steele and A. J. McEvily will appear in the Proceedings of the International Conference on Fracture Mechanics and Technology which was held in Hong Kong in March of 1977.

Fatigue Crack Propagation

The work on fatigue crack propagation has largely been related to the nature and significance of crack closure during fatigue crack growth under

constant amplitude loading as well as after an overload. As a result of this study two findings of significance have emerged. The first is that in the near threshold region of crack growth, a high closure load (of the order of 50% of the maximum load at R=0) is present in both the plane stress (surface) and plane strain (mid-thickness) regions of a crack growth specimen. In this region of crack growth Mode II type deformation (or Stage I) is occurring, and in this sliding mode, the tendency for the crack to open is reduced, and a high closure load is observed. Therefore the effective portion of the loading cycle is not only that above the opening load, but the lower loads are important as well and should be included in an expression for the rate of crack growth as a function of ΔK. At higher values of ΔK, that is above the first break in the $\Delta a/\Delta N$ vs. ΔK plot, the opening mode becomes the dominant mode, and in this region the closure level decreases. It is also in this region that a continuum model is appropriate, for below this range the structure sensitivity of the material is an important consideration.

With respect to overload effects, we have found that the surface region of the specimen is important in the retardation process. By machining away the surface layer, the retardation effect can be largely eliminated. It also appears that the overload effect induces two opening events which are thickness related; the first of these occurs in the plane strain region of the specimen, the second in the plane stress region at the surface. Since the plane strain region opens first on loading this portion of the crack tunnels ahead, and it is the drag at the surface which leads to retardation. The phenomenon known as delayed retardation is also related to this thickness effect. Our preliminary studies show that reduction in yield stress level and/or a reduction in thickness will lead to an increase

in the degree of retardation. There is a scale effect therefore which is of concern when extrapolating the results of small specimens to full sized structures.

The present program in this area involves the extension of this work to elevated temperatures as well as to other specimen geometries. The alloys being studied are Ti-6-4 as well as Ti-6-2-4-2.

Results of this phase of the study have been reported in two publications.

1. A. J. McEvily, "Current Aspects of Fatigue" in Metal Science, 11, 1977, 274-284. (Keynote Lecture of Fatigue '77 Conference held at Cambridge Univ., March 1977).
2. A. J. McEvily, "On Crack Closure in Fatigue Crack Growth," Proc. Fracture 1977 (Fourth Int. Conf. on Fracture, Waterloo, 1977) to be published. (Plenary Lecture).

In addition the paper

3. A. J. McEvily and J. Groeger, "On the Threshold for Fatigue Crack Growth" appears in Fracture 1977, Vol. 2, ICF4, Waterloo, Canada, 1977.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (19)
(18) AFOSR-TR-77-1305

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
(9) Annual rept.

4. TITLE (and Subtitle)
(6) FATIGUE CRACK PROPAGATION IN TITANIUM ALLOYS,

5. TYPE OF REPORT & PERIOD COVERED
1 Jul 76-30 Sep 77,
INTERIM

6. PERFORMING ORG. REPORT NUMBER
(14) UC-MET-5-1977

7. AUTHOR(s)
(10) A. J. MCEVILY

8. CONTRACT OR GRANT NUMBER(s)
(15) AFOSR-74-2703

9. PERFORMING ORGANIZATION NAME AND ADDRESS
UNIVERSITY OF CONNECTICUT
DEPARTMENT OF METALLURGY
STORRS, CONNECTICUT 06268

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
(16) 2307 (17) B2
61102F

11. CONTROLLING OFFICE NAME AND ADDRESS
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA
DEPARTMENT OF THE AIR FORCE
BOLLING AIR FORCE BASE, D.C. 20332

12. REPORT DATE
(11) NOV [redacted] 77

13. NUMBER OF PAGES
(12) 7p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

"Approved for Public Release; Distribution Unlimited"

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FATIGUE
FATIGUE CRACK INITIATION
FATIGUE CRACK GROWTH
TITANIUM ALLOYS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This Annual Report covers the period Aug. 1, 1976 through Sept. 30, 1977, and deals with the topics fatigue crack initiation and growth in Ti-6Al-4V forging alloy. Subsurface crack initiation has been related to the presence of severe dislocation pile-ups and perhaps to the influence of internal hydrogen. In the fatigue crack growth progress it has been shown that different mechanism are operative in various regions of the da/dN versus ΔK plot. The retardation effect associated with overload has been shown to be primarily a surface related effect due to the higher degree of crack closure which exists in the surface regions of a specimen.

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The Institute of Materials Science was established at The University of Connecticut in 1966 in order to promote the various fields of materials science. To this end, the State of Connecticut appropriated $5,000,000 to set up new laboratory facilities, including approximately $2,150,000 for scientific equipment. In addition, an annual budget of several hundred thousand dollars is provided by the State Legislature to support faculty and graduate student salaries, supplies and commodities, and supporting facilities such as various shops, *technicians, secretaries, etc.*

IMS fosters interdisciplinary graduate programs on the Storrs campus and at present is supporting five such programs in Alloy Physics, Biomaterials, Crystal Science, Metallurgy, and Polymer Science. These programs are directed toward training graduate students while advancing the frontiers of our knowledge in technically important areas.